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The thorax in history 6 Circulation of the blood

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Physicians and philosophers

We saw in the last article that the discovery that blood passes from the heart to the lungs and back again to the heart was the first break with the Galenic system of physiology. Galen's physiological scheme was the theoretical underpinning of his medical system and was directly related to his interpretation of the biological world. Both of these were still widely accepted at the end of the sixteenth century, and so to accept the pulmonary transit meant being based more firmly in theology than in Galenism, like Servetus, or modifying rather than rejecting the Galenic system, in the way that Colombo found Galenic answers to Galenic problems.

The other intellectual position available at the time was Aristotelianism. Although Aristotle had been far less precise and satisfactory in anatomy and physiology than Galen, and had said almost nothing on medicine, his teaching embraced the whole of the observable world, and his modes of argument and presentation of evidence reached from the syllogism to the classification of sea-mammals, and formed the basis of university education that every learned man, physician or not, assimilated up until the seventeenth century. Aristotelianism was presented as a logically interrelated whole in which each successive part of the curriculum was a development of the one preceding, from generally applicable modes of arguing to the simple motions of the inorganic world and from there to the nature of animals and man. The natural goal of all this was the complete description of the structure and function of man—in a word, the theory of medicine—one of the three or four[1] higher faculties (in our terms, postgraduate). But these higher faculties—medicine, law, and theology—were also *professional* and practical in leading to a career in civil or ecclesiastical life. University study of medicine normally led to membership of a professional college, where the interest lay more than in the universities on practical medicine; and despite the fact that medicine was a natural culmination of an Aristotelian education, its chief spokesman in both theory and practice was Galen. The physicians then had *professional* reasons for being Galenists: wishing to appear learned, their learning could consist only of Galen's teaching. Galenism became the professional orthodoxy of the professional bodies and the touchstone for the discovery and suppression of quackery.

So, for both social and intellectual reasons, the medieval disputes between Galenists and Aristotelians continued well into the seventeenth century. The Aristotelian notion that the heart was the centre of the body and therefore the source of the veins and arteries not only survived until Harvey's time but was very influential. Even the mistaken notion that Aristotle said the heart was the origin of the nerves[2] had a significant part to play in pre-Harveian physiological thought. For our purposes the most important Aristotelian doctrine still widely adhered to in the late sixteenth and early seventeenth centuries was that the arteries and veins (which Aristotle distinguished structurally but not functionally) arose from the heart. This cut across the Galenic notion of two distinct blood systems, the nutritive (venous) based on the liver, and the respiratory (arterial) centred on the air-breathing heart, a notion that in turn rested on a pre-Aristotelian idea that the basis of the blood system was a fundamental pair of vessels running the length of the body—the hepatic and splenic.

The physiological results of such Aristotelianism are seen in the works of the Italian peripatetic, Caesalpino,[3] whom Italian historians used to claim as the discoverer of the systemic circulation. Firstly, Caesalpino resolved the old question of the origin of the nerves by asserting that they were simply fine extensions of the arteries passing into the brain. This allowed him to accept the neo-Aristotelian cardiac origin of the nerves *and* the superior anatomy of the Galenists who described in detail the cranial nerves of which Aristotle had been ignorant. He was able to accept the physicians' account of the elaboration of spirits in the brain by means of the arteries. The *capillimenta* that link the incoming arteries to the outgoing nerves in the brain are a new type of vessel which recall strongly the structures described by Servetus in postulating the pulmonary transit (see previous article). Servetus had given primacy to the heart and blood for theological reasons, and Caesalpino for Aristotelian, but the result was the same—namely, that intellectual presuppositions had determined body function and this in turn, using the "eye of reason," had determined notions of invisibly small structures in the anatomy of man. As a device in physiological thinking, the eye of reason could not be dispensed with, and although several people objected to the existence of the Galenic pores in the cardiac septum because they could not be seen, they were obliged to postulate the existence of other invisibly small pores in the substance of the lung to account for the right-left transit of blood that could no longer pass through the septum.

Caesalpino is in a similar situation with respect to the second topic we need to examine in his writings.[4] He accepts the Aristotelian notion that both arteries and veins arise from the heart, but he also accepts Galen's description of the valves of the heart, which were unknown to Aristotle. The result is extremely interesting: the heart as the seat of the soul is connected to the sense organs, where the sensory capacities of the soul are exercised, in the manner described above (the nerves being extensions of the arteries). During the waking period the sense organs are supplied with innate heat and spirit from the heart, past the aortic valve and through the arteries and nerves, but in sleep, when the sense organs have less need of heat and spirit, and when the blood, cooled, seeks to sink back, then it is the veins that carry it back to the heart, in accordance with the structure of the valves of the vena cava at the heart. This is a clear, but limited, account of a circulation of blood. Its inspiration is the Aristotelian notion that hot things rise and cold things fall, applied to the specific requirements of the sense organs (and lungs, which in Aristotelian fashion cool the heart), but it does not relate this slow (daily) circulation to the motions of the heart, quantitatively or qualitatively. His account also accepts a greater-than-peripheral communication between arteries and veins and admits that blood crosses the cardiac septum. The relationship of this systemic circuit to the pulmonary is not clearly defined.

Harvey's background

Nevertheless, before the end of the sixteenth century there were in the physiological literature a concise and particular account of the pulmonary transit and a more general natural-philosophical description of a systemic circulation. Colombo's book was a university teaching text and widely known. Harvey made clear his debt to Colombo, but does not mention Caesalpino, and the question of Caesalpino's influence on Harvey is still disputed. A possible link between the two and the two sets of ideas is a commentary by Caspar Hofmann on Galen's most important physiological and anatomical text, *De Usu Partium*.[5] Like Caesalpino, Hofmann was an Aristotelian, as was Harvey. Harvey refers to Hofmann who in turn refers to Caesalpino. There was a neo-Aristotelian consensus in the pre-Harvey years in which the liver was divested of its function of generating blood, and the origin of the vena cava was placed in the heart. Sometimes the spleen played a part in these schemes as a homologue of the liver,[6] balancing it in a symmetrical arrangement around the heart. We may recall from the previous article the views of Varolius and Ulmus. The heart became the centre of the body, if not yet the centre of a circle with these Aristotelians, while at the same time the Galenists had largely adopted the pulmonary transit.

Hofmann elaborated his ideas in a book on the thorax and its contents, published shortly before Harvey's. His work is the culmination of the long history of the physician-philosopher debates, and its very title page indicates Hofmann's purpose in this matter.[7] He accepts the pulmonary transit, but of course finds an Aristotelian reason for doing so, claiming that the purpose of the lungs is to cool the blood, which is perfected and endued with innate heat in the heart. Hofmann is struck with the quantitative arguments that the pulmonary vessels are too large for the simple purpose of nourishing the lungs, and he extends the argument in examining the quantity of blood that must pass from the right side of the heart to the left at every systole, a quantity that could not be accommodated by any supposed pores of the septum. Harvey was to use this quantitative argument to great effect, but strangely, after reading Harvey's book Hofmann changed his mind about the argument, and claimed that ebullition of blood in the heart, like milk rising in a pan, made measurement meaningless. The repeated cycle of heating and cooling that took place in the heart and lungs, and that by which spirits were produced in the brain from the blood, was referred to as *circulatio*, a chemists' term for distillation (Caesalpino compared the brain to a chemists' retort) which, although not meaning circulation in the modern sense, is clear enough evidence of the Aristotelians' general conception of the *cyclical* processes of the body.

In distinction to the Aristotelians, the Galenists seem to have been more concerned with anatomical *minutiae*. André du Laurens, Jean Riolan, and Caspar Bauhin were writers of anatomical textbooks which were popular in the pre-Harveian years and which Harvey himself relied on to a considerable extent. Bauhin, like Harvey's teacher Fabricius of Acquapendente, was concerned in the discovery of valves in parts of the body other than the heart, and as we saw in an earlier article the discovery and *interpretation* of the extra-cardiac valves (particularly those of the veins) were fundamental in setting the scene for Harvey. Riolan became involved in the professional Galenic orthodoxy of the Paris Faculty of Medicine and insisted on the existence of the Galenic pores in the cardiac septum in a heart boiled for a long while.[8] Like Hofmann, he became a notable opponent of Harvey's ideas but under their influence suggested an alternative scheme of circulation, involving anastomoses between major vessels to allow a central circulation to proceed, but preserving Galenic physiology undisturbed in the outer and peripheral parts of the body. This gratuitous postulation of gross anastomoses was a heavy tread in the sensitive area of arterial-venous communication. Harvey could not see his channels of communication any more than the Galenists could see cardiac pores in a fresh heart, and, as we have seen, to deny cardiac pores meant using the eye of reason to establish invisible pores elsewhere, whether in the lungs or in the flesh of the body. Harvey realised his methodological position here was open to attack, and where he could do so he avoided "anastomoses" and rose to a rare defence of his notions against Riolan.[9]

There was no commonly agreed idea of how the heart worked before Harvey. The Aristotelians differed profoundly from the Galenists, and the Galenists were divided among themselves on the question of the porosity of the septum and the pulmonary transit. Yet amid this confusion medicine still had to be taught, examinations passed, and professional colleges entered. The result was that a new formal course of medicine was hammered out from these disparate elements, which combined Aristotelian natural philosophy, Galenic anatomy, and Hippocratic practice. The devices used to reconcile these three authors recall those of the middle ages, and we may call this late sixteenth and early seventeenth century school medicine "neoscholastic" in contrast to the earlier humanism of Vesalius.[10] The anatomical textbooks of Crooke,[11] Bauhin,[12] and Du Laurens[13] present an assimilated text and consign all the problems—the irreconcilable differences between the ancient authors and the new discoveries of the time—to margin notes or separately listed *quaestiones*. The new generation of anatomists, who put themselves and their discoveries on an equal footing with the ancients—Harvey scornfully called them "neoterics"—had since the time of Vesalius accummulated a great deal of anatomical and physiological information which had been unknown to the ancients and which was in many cases inimical to their ideas.

Harvey

There was no simple orthodoxy against which Harvey reacted, and indeed he had a very rich field of speculation—including a notion of circulation—to draw on. He was himself an Aristotelian, rather than a Galenist or a neoteric, but his use of Aristotle's sound scientific methods produced a result that was dramatically new, and brought opposition from all three groups. I do not propose to give a detailed account of Harvey and his work, for he is a figure who has attracted as much attention from historians as any in the history of science.[14] Rather, we must see how his work fits into the background described in earlier articles.

Harvey's book of 1628[15] is set out in the formal style of a university dissertation, and the sequence of topics tells us nothing about Harvey's own progress in his discovery. We are left with his remarks to Robert Boyle, found also in a communication to Riolan, that it was a consideration of the valves in the veins that first gave him the idea. We have seen before that the traditional notion of a valve was Galenic, and it included the idea that some material always flowed back across the valve in the "wrong" way. The analogy of mechanical, water-restraining valves that did *not* allow a back-flow was not used in physiology until the late sixteenth century, and the English word "valve" expressing this idea did not enter the language until shortly before Harvey in an anatomical digest that he certainly read. Already convinced by Colombo's description of the pulmonary transit, and believing with other Aristotelians that the veins arise from the heart, Harvey would have quickly seen that to admit the competence of the venous valves was to reverse the direction of bloodflow in the veins, returning venous blood to the heart from the tissues, whence it had been delivered from the heart by way of the arteries.

In his formal exposition of his argument in *De Motu Cordis* (as well as in the earlier Lumleian lectures) Harvey approaches the question of circulation by insisting on the forceful systole of the heart, against Galen. Galen had said the heart was not of the same muscular nature as the skeletal muscles, and did not act in the same way. Harvey, at least in his earlier days, retained a belief in the three kinds of fibre[16] of which Galen said all hollow organs were composed, although he was sceptical of the attractive and retentive function given to the straight and oblique fibres respectively by Galen. This doubt probably came from Fallopio, under whose criticism Vesalius quite abandoned the notion of the three sorts of fibre. Harvey, in the book of 1628, denies that the heart is made up of these three sorts, as contemporary thought held, but says that the wall of the heart and the septum consist of circular fibres, while the "armlets" (*lacertuli*)[17] consist of oblique fibres serving to pull the apex of the heart to its base. *Lacertuli* for Harvey were the longitudinal fibrous structures of the ventricles which he suggests misled Aristotle into imagining that the "nerves" arose in the heart. Harvey's emphasis on the sphincter-like circular fibres of the heart was designed to refute the idea, illustrated by Vesalius with the analogy of osiers and rushes made into the shape of a pyramid,[18] that the heart contracted by its longitudinal fibres only and thus expanded at its girth while the apex was pulled towards the base, becoming more capacious.

Harvey also substantiates his argument that the heart is a muscle by reference to the Hippocratic *On the Heart*. It will be remembered from my first article that the author of this book clearly said that the blood of the right ventricle is *prevented* from reaching the left ventricle, the seat of the mind; the septum was not thought to be pervious. Probably the septal pores were purely Galen's invention, introduced to explain his strenuously argued claim that the arteries contain blood and not spirit alone. We have already noted the possiblility that it was a perusal of some such pre-Galenic work on the anatomy of the heart as the Hippocratic *On the Heart*, combined with Galen's credible blood-filled arteries, that convinced Ibn al Nafís of the pulmonary transit.

Having established the heart as a muscle, Harvey proceeds to show that the arteries are filled passively, and that the pulse is not an active phase of expansion along the arterial coat from the heart, as Galen had said. Following this, Harvey argues for the pulmonary transit of blood, using Colombo's anatomical observations of the presence of blood in the pulmonary vein and left ventricle, the size of the pulmonary vessels, and the arguments we have met before. The clinching anatomical arguments for the pulmonary transit are the non-porosity of the septum and the structure of the cardiac valves. Harvey alludes to the notion that the septum is porous, "But, damme, there are no pores and it is not possible to show such"[19] ("Sed mehercule porositates nullae sunt, neque demonstrari possunt").[20] Franklin translates Harvey's *caecae porositates* as "invisible pores," but it is perhaps more likely that they are the visible but not perforate pits (that is, "blind") on the septal wall that were admitted by all anatomists, but which Galen said *were* porous, as seen by the eye of reason. At all events, Harvey is thus put into the position of denying pores to the septum because they are not visible, but accepting pores in the flesh of the lungs (and body) that are equally invisible, but which were defensible in terms of authority and reason, arguments that anatomists since Galen had always used, and with which Harvey's opponents were as well equipped as he. By the idea of the pulmonary transit, the anomaly of the artery-like vein and the vein-like artery is resolved, and Harvey argues energetically for the close correlation of structure and function: the venous artery is a vein not only in structure but also in function. If it served to carry air (as contemporary but not classical Galenism held) why did it not have the structure of the harsh artery, that is, the trachea?[21] Why suppose that the two sides of the heart have quite different functions, the one sanguineous, the other spiritual, when the structure of the heart clearly shows it to be one organ? How can the lungs and windpipe have the same function as the left side of the heart when their structure is so very different? With Harvey came the final disappearance of the ancient idea of two fundamental vessels and systems, the venous (nutritive) and arterial (respiratory) that we met in the first article.

Having announced the pulmonary transit, Harvey turns his attention to the remaining matters—namely, the amount and the source of blood passing through the heart and lungs. He tells us that in attempting to discover how much blood passed through the heart, he undertook many animal vivisections, and devoted his thought to the symmetry and size of the ventricle and vessels.[22] He pondered too on the skilfully-contrived valves and fibres,[23] and arguing like many before him that Nature does nothing in vain, he concluded that the amount of blood passing across the valves in the direction they allowed was greater than that which could be supplied from ingested food or absorbed as nutriment by the body. His method of estimating the amount of blood passing through the heart was partly anatomical in that he began with the quantity of blood held in the relaxed left ventricle: he says that he has seen two ounces in the human body. He then estimates the volume of the contracted ventricle and calculates from the difference the amount ejected at each systole. The latter quantities are entirely theoretical, and Harvey, perhaps deliberately, remains imprecise. He takes his own lowest estimate and still shows convincingly that even an eighth part of the blood contained in the relaxed left ventricle, ejected during contraction, soon totals a very large amount by the heart's repeated action. His only other direct measurement at this stage is to discover the total amount of blood in a sheep, by way of showing that the whole mass of blood must circulate in a comparatively short time.[24]

Having argued so convincingly for the circulation of the blood, Harvey was then faced with an anatomical problem. How did the blood, reaching the fine terminations of the arteries, pass over to the fine venules to be carried back to the heart? The capillaries are of course invisibly small to the naked eye and, unable to employ Aristotle's principle of observation, Harvey was forced to employ two techniques used by anatomists for a long time —the eye of reason and reliance on authority. Harvey is hesitant about postulating direct anastomoses between arteries and veins, even on the smallest level, but his arguments for some kind of passageway are like those used by the champions of the pulmonary transit. The texture of the liver and kidney is far denser than that of the lungs, yet no one denies that the former two organs allow the passage of great quantities of fluid; why not in the case of the lung also? Harvey speaks of the "porosities"[25] of the lung, and avoids the idea of a vessel-to-vessel contact. As we have seen, Harvey later wanted to deny any connection with Riolan's ideas, and in a letter to Schlegel he totally denies the existence of anastomoses "as such are commonly understood".[26] He elaborates this by explaining that arteries are much smaller than veins and that the two types of vessel cannot therefore meet mouth to mouth. Any such connection would be rather like the insertion of the ureters into the bladder, but Harvey prefers to think in terms of "pores of the flesh," the implication being that blood is extravasated between the arteries and the veins. The problem is really one of terminology: Harvey is prepared to accept that some arterioles may enter a venule in the manner of so many ureters inserted into a bladder, but he does not want to call such a junction an anastomosis. "I do not believe it to be advantageous to the philosophic principle to decide something about the works of Nature from the meaning of words, or to summon anatomical disputes before the grammatical tribunal."[27] He rejects the normal mouth to mouth inosculations of the ancient tradition because he cannot see them, except at three locations—the cerebral choroid plexus, the spermatic preparative veins and arteries, and the umbilical veins and arteries.

In this letter, however, he has been driven to elaborating his ideas by criticism and inquiry. In *De Motu Cordis* he used a large quotation from Galen's *De Usu Partium*. In all of the body, says Galen "the arteries and veins communicate with one another by common openings and exchange blood and pneuma through certain invisible and extremely narrow passages."[28] Now here Harvey cannot observe the invisibly small pathways, and is obliged to rely on reason and authority. His Authority is Galen, and Harvey makes no objection to Galen's use of the term "anastomosis," or rather, the use of the term in Gadaldinus's edition of Reggio's translation, which is the version used by Harvey.[29]

Although Harvey's admiration of nature sometimes seems to be as great as Galen's, he seems freer of the dominating influence of the idea of the perfection of nature as a divine craftsman. There seems no providential reason why the body should vary as much as Harvey's observations told him it did, sometimes passing beyond the boundaries of "normal" variation and approaching the pathological. He was "frankly amazed" that there could be so much variation in the structure of human hearts, and like Sylvius held that at least some change had occurred since Galen. If nature did nothing in vain she was nevertheless bound by certain constraints, and was sometimes not quite as careful as she might have been. She was constrained not only by simple necessity, such as not being able to locate two organs in the same place, but also by considerations of the nobility of organs, so that in the event of a change taking place in the body over a long period, the less noble organs had to adjust their position to accommodate the more noble, as the human kidneys had moved by reason of the more noble liver. In the microcosm, as in the macrocosm, "the weakest to the wall";[30] the least noble organs suffer all those above, and the heart was the most noble of all, the sun of the microcosm.[31] Sometimes Harvey seems to imply that variation in the body, for which there does not seem to be any providential purpose, is due to nature's hastiness or carelessness. The situation of the guts is uncertain and variable, for nature "Romidges (rummages) as she can best stow";[32] the cardiac valves do not "appear to have been made with equal skill in all animals in which they are present. In some they are made relatively carefully, in others relatively slackly and carelessly,"[33] ". . . *in aliis remissius & negligentius.*"[34]

The principle that nature does nothing in vain but yet was sometimes rather careless goes hand in hand with Harvey's suspicion of reason and his emphasis on empirical observation. We have seen that Galen "saw" the pores of the interventricular septum with the eye of reason by deducing their existence from the axiom that nature does not make a structure without purposes, and a similar mode of reasoning was often used by other anatomists. While Harvey may have been led to the idea of circulation, as he told Boyle, by considering the purpose of Nature in the design and position of the venous valves, yet he was always hesitant, because of Nature's occasional negligence and the observed variability of the body, to reverse the procedure and assume that an organ *must* have a particular form to accord with a purpose of Nature.

Harvey also shows his dislike of reason in refusing to acknowledge that his description of the circulation was incomplete without its final cause. His opponents criticised him for this, that he had described *how* the blood moves, but not *why*, and he replied in the second essay to Riolan that it was enough in the first instance to establish that circulation occurred and later to investigate its purpose.[35]. The true method of procedure, says Harvey, is observation "stabilised" by reason; through a study of the sensibly manifest, abstruse things become better known. This is fundamentally Aristotelian, and Harvey's views on scientific method, the relative roles of observation and reason, are largely Aristotle's.[36] Harvey's words on this in *De Generatione Animalium* refer to the need to keep one's universal concepts in good order by repeated observation and induction. On the other hand, the Aristotelian method of syllogism is "mere dazzle"[37] leading to sophistries, and sophistry breaks up against sense like the waves of the Sicilian sea against the rocks inside Charybdis.[38] In his letter to Hofmann, Harvey refers indirectly to himself as an analytical philosopher proceeding from "facts" to causes. We have seen before that the term analysis in academic anatomy was used almost entirely in connection with teaching, proceeding from the appearance of the whole body often by means of dissection to the nature of its constituent parts, its similars, humours, qualities, and principles. The reverse procedure of synthesis was also a teaching method, beginning with those things shown by analysis. Harvey almost certainly called himself an analytical scientist[39] because he followed Aristotle's method in the *Posterior Analytics*;[40] here Aristotle recommends a progress from singulars, most readily known to the senses, to universals. The idea as used in academic anatomy does not come directly from Aristotle, and although there are some similarities, its lineage is involved. One difference is immediately clear: Harvey is using the term analysis to indicate a mode of research by which new truths may be discovered, not a method of teaching. A neat contrast is provided by his opponent Riolan, who discusses the matter in his commentary on Galen's *De Ossibus*. This is expressly a didactic and defensive exposition of Galen's osteology, and since, Riolan claimed, Galen wrote only what is true or probable[41] it is an underlying assumption of Riolan's discussion that there is little possibility of making new discoveries. Synthesis, he says, is the best method of teaching, while analysis "confirms and demonstrates to sense *what the first taught theoretically.*"[42] For Riolan synthesis and analysis form a teaching and learning method that runs in a circle, beginning and ending in theory. Analysis is secondary, confirmatory, and didactic. For Harvey analysis is a method of scientific investigation used in the discovery of new truths, passing from singulars most apparent to the senses by induction to universals and true knowledge.

Mechanism and the new philosophy

Enough has been said on the traditional elements in Harvey's thought, his Aristotelian methodology, and fundamental concept of life. But Harvey lived through one of the most significant periods of intellectual change in the history of science, and by the end of his life the intellectual landscape around him had changed almost beyond recognition.

Descartes was a contemporary of Harvey, and somewhat grudgingly accepted, and then modified, the idea of the circulation of the blood. Both consenting to and modifying the idea were done in the interests of Descartes' world-view, with interesting results. Descartes had early decided that all contemporary education and knowledge were worthless, and that future progress must be built on surer foundations. He consequently returned to fundamental principles of metaphysics and, largely deductively, created a world-view that was profoundly different from the neoclassical synthesis of the schools (though curiously similar in some superficial details). The system rested on the mutual exclusiveness of soul, non-extended and thinking, and matter, extended and non-thinking. In the body the soul was responsible for the intellectual operations and voluntary motion. All other bodily activities were the necessary result of the disposition of the matter of the body, or in other words they were mechanical. Animals, lacking souls, were simply machines.

The idea fitted well into the developing new philosophy of the seventeenth century, which rejected Aristotle's qualitative physics and reintroduced the concept of atoms, or at least fundamental particles, that had been so objectionable to him and to Galen. The notion grew up that ultimate reality lay in matter and motion, both of which were measurable and could be handled by the aid of geometry, the only certain science. Aristotle's Qualities and Galen's Faculties were labelled "occult" because their mode of operation could not be understood in the new reductionist framework.

In Cartesian physiology,[43] then, only voluntary motions were dependent on the soul, and there remained a large group of unconscious "vital" motions over which the soul had no control and which were relegated to machinery. The most important of these was the beating of the heart, which despite Descartes' fresh start remained a fundamentally important organ, the source of all motions in the body. Descartes accepted that the blood circulated, but claimed that the mechanism of the heart's action was not a forceful systole, as Harvey and Erasistratus has said, but a forceful diastole, as Galen had said. Of course, Descartes rejected Galen's notion along with all the other apparatus of antiquity, and inserted in its place the idea that the blood entering the heart vapourised by the heat of a fire-without-light placed there by God. The subsequent expansion forced open the arterial valves and the blood issued into the body, where it condensed and returned in liquid form to the heart. Now, although Descartes insisted that the fire-without-light was a *natural* fire, much like the heat arising in wet hay or by other natural processes, he could make it really credible only by assuming it was the direct gift of God that maintains or originates it, which is not very different from the traditional innate heat of the heart of almost every Greek writer.

In a similar way Descartes described nervous spirits in purely mechanical terms. He said they consisted of fine particles, drawn off from the blood by the rapidity of their motion in accordance with his laws of motion. Those travelling fastest rose to the brain as the simple result of their velocity, and there constituted the nervous spirits, which occupied the nerves and were the agents of sense and motion. The result is not very different from the contemporary or classical concoction of animal spirits from the blood in the brain, except that Descartes has provided a model for the explanation of bodily motions that could be indefinitely extended and modified.

Descartes' continental influence was considerable, particularly in France. In England Harvey's work was accepted before Cartesian mechanism in physiology was widely known. In conscious emulation of Harvey there grew up an English school of physiologists who attempted to be experimental and inductive, without any sharp break with the scientific ideas that had made Harvey so successful. Harvey's influence also meant that several able men were investigating further the problems of circulation and the action of the heart.

One of the most important of the "Harveians" was Francis Glisson, who carried devotion to traditional ideas to the point of reaction against the ever more apparent Cartesian mechanical revolution. He is best known for his work on "irritability"—the innate power of the muscle to contract. All matter, said Glisson, is essentially to some degree alive and *capable of motion.*[44] This simple power exists through a whole hierarchical range from inorganic matter to the rationality of man; in all cases motion presupposes desire, and desire presupposes perception. Glisson's "simple perception," "natural appetite," and motion are a chain of events that involve *sensation* only at the level of material organisation that provides sense organs, and which involves conscious volition, appetite, and perception only in the self-conscious mind of man. Glisson's hierarchy related directly to the traditional grades of soul, the vegetative, sentient, and rational, and his language of causality, matter, and form is that of the schools. Simple and compound perception and appetite are terms elaborated in the same context into current doctrines of moral philosophy. All this, and particularly unconscious perception and the primeval life of matter, was incomprehensible to the Cartesians, for whom all actions of the soul were rational and conscious and all matter was soulless and lifeless. It was, however, much more acceptable in England, where there had been no Cartesian break with past ideas and where there was a greater audience for providential explanations. Cartesian corpuscularity was open to the charge of atheism, as Descartes himself felt, just as Aristotle and Galen had railed against the atomists of their time by declaring that there could be no Purpose, no Final Cause, no evidence of a skilful creator in a mindless, fortuitous concourse of atoms. In England it seemed that the soul was not only the vehicle of personal immortality but the essence of life and motion in the body.

All this is necessary background to an understanding of post-Harveian work on the heart. Indeed, the heart proved to be a critical case in the presentation of mechanical and opposed explanations of life. It was the most obvious and necessary of the vital actions, yet was clearly outside the control of the conscious and rational soul. More, it continued to beat for a while after being excised from the body (the beating of separated vipers' hearts was a scientific curiosity of the time) and so was absolutely removed from the soul in the brain: was this not good evidence of mechanism? Yet on the other hand the heart was greatly disturbed in moments of emotion (which was exercised by the soul) and it adjusted itself to the needs of the body (it was widely held that the increased pulse of fevers was part of the living body's attempt to throw off the morbific matter): were these not powers far above those of mere mechanism?

The dispute continued for at least a century and a half after Descartes had introduced the idea of a mechanical body. By the end of the seventeenth century it looked as if mechanism was to become the new orthodoxy of medical theory.[45] The pumping heart and the circulating blood had become the central physiological interest. They lay behind other suggestions, such as glandular secretion, supposed to be effected by the differential secretion of particles of different sizes or shapes in different glands, depending on the velocity of the particles, or their shape and the shape of the pores in the glandular filter. Given the fact of circulation, certain residual technical questions were left to be answered. Was the heart capable of sustaining the entire circulation, or did the small arteries assist by the contraction of their muscular coats? More briefly, what was the force of the heart? The question was tackled by the Italian mechanist Borelli, but the physics of the time was incapable of formulating the problem, and Borelli's answer was an impossibly high figure, expressed as weight, while the motion of the blood leaving the heart was thought of in terms of projectile force. The body was increasingly thought of as a hydraulic machine and the proper physiological questions were ones of viscosity, friction, velocity, pressure, and all those associated with the passage of fluids through tubes.

This standard interpretation did not contain Descartes' fire-without-light in the heart, and instead the heart was regarded as a muscle like others in the body, as Harvey had maintained against Galen. But the standard mechanical picture of the body explained muscle contraction by assuming that muscles were hollow sacs or chains of cells of some specified geometrical shape, and that contraction was effected by the nervous spirits inflating the cells and so broadening their width while contracting their length. But the nervous spirits, being purely mechanical and with no motive force of their own, derived all their power from the circulating blood, from which they were mechanically derived. The blood itself derived its circulating force from the heart, which like other muscles was supposed to derive its contraction from an influx of nervous spirits. It is surprising to us that this perpetual motion machine was accepted without difficulty by several mechanical physiologists in the late seventeenth century. It is true that some began to see the problem of where the motion was coming *from*, given that the perpetual circuit must in fact constantly lose motion by friction and muscular activity, but before the problems were fully articulated another influence, as great as that of Descartes, altered biological thinking: the influence of Newton.[46]

It took about half a century—the first half of the eighteenth—for physiologists to assimilate Newton. Most medical men could not understand the *Principia*, but the *Opticks* (in particular in English) contained a number of broad hints as to how Newton thought the body worked. English physiological theory was at once filled with ether and particles; vibrations of the first, and short-range attractive and repulsive forces of the second being used to explain nervous transmission, muscular motion, and all "fermentative" or chemical actions. Later there came some recognition of Newton's physics, the questions of mass, momentum, and the forces necessary to produce or alter motion. Before this physiology had been kinematic or qualitative, and now it became by degrees dynamic and quantitative.

This change from kinematic to dynamic physiology gave a curious twist to the established positions mentioned earlier. Those who, like Glisson, accepted a more or less traditional notion of a soul in the body, and held that the material soul was essentially alive and that motion was the principal attribute of life, now found that the question of the origin of motion in the body was self-answering: motion *was* life. Yet mechanism, both Cartesian and Newtonian, did much to encourage the idea that matter was essentially inert and had to be moved by external forces. So if the body was a machine, there was an obvious need for an external supply of motion to make the machine work. Now that Newton had shown how to measure motion in relation to matter, and that motion was being constantly lost in the universe from friction, collisions between moving bodies, and so on, quantitative considerations showed too that the body's motions needed constant replenishment. Newton had suggested that macrocosmic motion was replenished by gravity, natural fermentations, and other actions, probably motivated by the omnipresent ether, but those who transferred the problem to the microcosm generally thought that the body was moved by the soul. The paradox is that it was these traditional "animists" who used quantitative arguments in a penetrating way. The more they could show that the body was a true hydraulic machine the clearer it was that it needed an external moving force. The traditional "mechanists" on the other hand denied, in the Cartesian tradition, that the soul of the body did anything more than think. They were driven to postulate that the motion of the muscles was due to some natural or God-given force innate in the muscle itself, a force resulting either from the complexity and disposition of matter itself, or from a divine *fiat*. Again the question of origin and quantity of motion to a certain extent answered itself, and the physiology of the traditional mechanists was qualitative and kinematic, without even the emphasis on the body as a hydraulic machine that is found in animist writings.

The heart was central in this problem. In the immediate post-Newton period the Scot Pitcairne set up the hydraulic machine model of the body for other Newtonians in Britain. Keill, Jurin, and Hales worked on the force of the heart and exemplify a change in the practice of Newtonian science from the mathematical (the influence of the *Principia*) to the experimental (that of the *Opticks*). Hales was the most experimental and determined the blood pressure of a horse by inserting a tube into the crural artery and observing the height of the column of blood in the tube. Hales was perpetual curate of Teddington on Thames and had a very English view of the rationality of the Creator and his Creation. It may well be that natural theology of this kind encouraged several English thinkers, who had never quite forgotten the traditional motive faculty of the soul, to occupy animist positions in the post-Newtonian period. Newton's own circle included a number of Scots also, who may have shared these ideas.

The situation on the Continent was different, with the one exception of Montpellier. Here mechanical doctrines were orthodox until 1735 when François Boissier de Sauvages began to teach that the body was a true hydraulic machine and that as a result it, and particularly the heart, must have a supply of moving force, which could be nothing other than the traditional soul of the Greek medical writers and the Christian fathers. In particular the soul was the "healing power of nature" of the Hippocratics, and animism could lead away from the absurd speculations of the mechanists to a new Hippocratic empiricism. The earlier mechanical teaching at Montpellier, in an effort to introduce Newtonian ideas, had for example explained the motion of the heart on the basis of "libration." While the direct meeting of equal masses moving at equal velocities was assumed to result in total loss of motion, their indirect meeting was held to produce constant oscillation about a point. The heart was said to move in a libration of this type as a result of all the forces acting upon it: blood entering, blood leaving, gravity, pressure from the body, and so on. The result was said to be true perpetual motion, without any internal or external input. Consequently the dynamic problem of the origin of motion was missed, no account was taken of loss of force in friction, and the whole problem remained essentially qualitative without any attempt to quantify the forces said to be in action.[47]

The soul and machinery of the heart

As suggested above, the heart was a critical case in any explanation of animal motion, mechanist or animist. Although widely accepted to be a muscle, it was clearly not under the control of the will, and more importantly it beat with a unique alternate motion. Its beat also continued for a while after excision from the body. The Galenic Pulsific Faculty satisfied no-one, and the Cartesian alternate ebullition and condensation did not prove popular (although a similar hypothesis was adopted by Harvey's opponents to nullify his quantitative arguments: Riolan, Hofmann, and Primerose).

One answer was chemical. It was developed by post-Harveian English physiologists in Oxford who worked on the heart and on respiration. Boyle and others recognised similarities between combustion and respiration, and although oxygen as a distinct element was not discovered, many processes of what we call oxidation found a common explanation in the new particulate natural philosophy of the time. Lower worked on the heart, but it was Thomas Willis, Sedleian professor of natural philosophy at Oxford, who constructed an entire scheme of physiology from the iatrochemistry of the time. The contraction of muscles was accounted for by the effervescence of two particulate "spirits" meeting in the cavities of the muscle, expanding its width and contrasting its length. One of the spirits was derived from blood and was resident in the muscle and the other was sent down the nerves upon a command from the soul; this spirit had features in common with the "nitro-aerous" spirit of respiration. Nervous spirit emanating drop by drop from the nerves ensured the alternating contraction of the heart. To a certain extent this answered the dynamic problem of the source of the power of muscular motion by referring it to a chemical reaction, but for Willis, writing in the middle of the second half of the seventeenth century, the problem was not heightened by Newtonian physics. Although adopting completely the corpuscular philosophy of the seventeenth century, Willis was no mechanist. He claimed that man had two souls, a higher rational *animus* occupying the nervous system, and a lower material *anima* possessed in common with animals and responsible in a traditional way for some of the sentient and vegetative faculties. It was all an English compromise between old and new, and we can see from Willis's preface to his book on the brain and nerves[48] that his animistic notions were bound up through a natural theological argument with traditional Christian views.

Another and more directly animistic answer was put forward, surprisingly enough, by one of the most influential of all mechanists, the Italian Borelli. Borelli had very successfully applied the principles of mechanics to the gross movements of animals by considering their limbs as levers and so on, but his attempt to produce a micromechanics of muscular motion was less successful. It was again a question of a hypothetical geometry of structure, which he used to show the direction of a kinematic transfer of motion. But the ultimate *origin* of motion was much more difficult to explain, and Borelli was driven to conclude that the motive force of the heart was the same as that of the voluntary muscles, which were moved, without question, by the will, a faculty of the soul.[49] Borelli supposed that the embryonic heart at the earliest stage of development could transmit to the soul its perception of the heaviness and heat of the blood that filled it. The soul, although at this stage not rational or conscious, was nevertheless able to act in the best interest of the body, and it accordingly generated within the heart a motion designed to remove the unpleasant sensation arising from the contained mass of blood. This first contraction of the heart expelled the blood into the embryonic arteries. The heart was filled again from the veins; again the soul acted, and the future pattern of systole and diastole was established. Before long the motion became habitual to the soul, so that the unpleasant stimulus was no longer felt and the response was automatic, in the same way as a harpsichordist plays a piece perfectly without being aware of the motion of each finger in turn. Borelli makes it clear that this original action of the soul to remove an unpleasant sensation was exercised by the faculty with which the soul avoided Evil and pursued Good in general. His terminology is that of the standard moral philosophy or "psychology"[50] of the time and closely related to the Simple Perception, Appetition, and Motion of Glisson and to the animists' notion that fever was the soul's effort to rid the body of noxious matter.

This doctrine of action and reaction was developed by both animists and mechanists in the eighteenth century. In both cases the "simple perception" of Glisson or Borelli became "stimulus," and the mechanists vigorously denied that *any* sort of perception was involved. They insisted that the response to the stimulus was purely mechanical, much as Descartes had described a mechanical reflex action in which the nervous spirits from the sense organs were literally reflected at the pineal gland in the brain into motor nerves. It was indeed a part of the Cartesian inheritance to deny any soul-directed activity, including simple perception, at any level lower than the conscious rationality of man. The animists claimed that the stimulus was perceived at a non-conscious level by the living powers of the tissues and that the resultant motion was "wise" either in exhibiting the habituated action of flight-from-evil, as in Borelli, or in reflecting the wisdom of the Creator in having united the soul to the body according to certain fixed and beneficial laws.

It was this dispute on the topic of sensitivity that sharpened the distinction between the various kinds of non-conscious motions—the "vital" or "involuntary." Reflected, or reflex, actions were generally admitted to be simple, whether mediated by simple perception or mechanism. They were invariable and beneficial, and in terms of the experimental results obtained by both schools of thought eagerly trying to demonstrate their own theoretical positions, in all major aspects reflex actions were the same to both parties. Secondly, there was a traditional group of actions known as "sympathetic." These involved a greater degree of co-ordinated complexity, both physiological and pathological. These motions were apparent mostly in the abdominal viscera. They had traditionally been accounted for by the movement of humours and by "occult" explanations like similarity of function of the sympathising parts, similarity of origin, similarity of substance, spatial proximity, and the use of communicating structures like membranes, blood vessels, fibres, and nerves. The debate about sensitivity was immediately relevant because all except extreme mechanists allowed that sympathy included some kind of *feeling* that was not necessarily perception or sensation. The debate, and particularly the work of Haller, Whytt,[51] and others, established that the nerves were the only sensitive parts of the body and that the muscles were the only "irritable"—that is, contractile—part. That the nerves serving the sympathising organs of the abdomen were of a type different from other nerves had been recognised by Willis, but it was not until the 1720s that Parfour du Petit showed that the sympathetic nerves were not cranial nerves. French anatomical texts like that of Winslow soon described the sympathetic nervous system as distinct from the central nervous system, although Haller was still looking for the cranial "origin" of the sympathetic trunk later in the century.

The most widespread of the mechanical ideas about the beat of the heart was that of the "medical teacher of all Europe," Hermann Boerhaave. He supposed that the nervous spirits passed down from the brain to the heart through nerves which, before entering the muscular substance of the heart, passed down between the ventricles. When the spirit reached the muscular substance, contraction ensued and the nerves were compressed, thus halting the flow of spirit; the cardiac muscles consequently relaxed, and the spirit flowed once more. It was difficult to account by this theory for the alterations in heartbeat that accompanied fever, exercise, emotional disturbances. and so on, and Boerhaave's pupils abandoned the idea. Haller[52] replaced it with a form of the stimulus and response theory, in which the entering blood aroused the irritability of the ventricles. The response was in proportion to the stimulating nature of the blood, which in fevers carried acrid particles, increasing the pulse rate. Whytt, from an animist viewpoint, argued that some emotional disturbances increase the sensitivity of all parts of the body, and so the same stimulus of blood in the heart produced a greater response.

Vitalism

Although considering themselves profoundly opposed on theoretical principles, the animists and the mechanists for all practical purposes arrived at essentially similar results. The animists, paradoxically insisting that the body was a pure machine, in order to prove the necessity of a constant supply of dynamic force to move the inert matter of the machine were obliged to admit that this supply, the soul, acted according to fixed laws. The mechanists, more aware of dynamic problems after Newton but refusing to accept an incorporeal source of power, postulated natural forces arising in matter as a result of its complexity. In other words they denied the inertness of matter and discussed innate powers like Haller's irritability or *vis insita* which, he said, was natural but God-given. These biological properties were closer to a position long since abandoned by the animists, that of Glisson's innate forces of matter. They were unquantifiable and diverted biologists' minds away from the dynamic and mathematical problems faced by the later animists.

In this way both parties had to a certain extent occupied each other's territory in theory, and in practice had reached similar conclusions. Towards the end of the eighteenth century the theoretical positions were abandoned, and almost the entire medical world reached some sort of consensus that we can call vitalism. The most objectionable aspect of animism had been that the immortal and immaterial soul should directly concern itself with mundane physiological activity, and the most repugnant aspect of mechanism was that the body was a mere machine. Vitalism involved the assumption that the uniquely biological properties were the characteristics of essentially *living*, but not animated, matter, that they were unique to physiology, which was thus not dependant on physics as it had been in the periods immediately after Descartes and Newton, and that they were natural and not divinely imposed upon matter any more than the simple physical qualities of gravity and elasticity.

Animism had always had the advantage over mechanism in that it had a ready answer to questions about the beneficial result of most biological actions—that is, that they seemed guided towards the good of the animal in differing circumstances. Early and extreme animists like Stahl had insisted that the soul was essentially free, not bound to the body by laws, and able to lead the body in the best possible way (or even irresponsibly). When mechanists faced the problem their answer was that the original *design* of the body was that which ensured its continued and adaptable operations. In a similar way the early vitalistic theories involved a notion of a guiding force intrinsic to the body, promoting embryonic development and adapting the body to new circumstances. Throughout the nineteenth century this idea was whittled away—for example, by the discovery that organic compounds can be synthesised artificially from inorganic components—until after Darwin it became possible to refer all biological activity to original design in the evolutionary sense.

General conclusion

In these articles we have examined ideas on the structure and function of the thorax and its contents, and in particular the heart, over a period exceeding two thousand years. On reviewing this period the most striking thing is the continuity of these ideas. Harvey turned to Erasistratus to support his case against Galen, and the general effect of Harvey's discovery was to overturn the ancient idea of two separate vascular systems in the body, the nutritive and respiratory. In seeking a non-mechanical explanation of the beat of the heart the eighteenth century animists turned to Hippocrates. The discovery of the circulation of the blood was a conspicuously successful piece of seventeenth century science, and one in which we can see so many features of modern science that the interest of the historian of science is drawn to the development of modern science. Science, in medicine and in other fields, is a dominant feature of our society: how does it compare with that of earlier ages?

We must first avoid the superficial conclusion that our predecessors were simply credulous monks or teachers who accepted without question the surviving words of the ancients, a conclusion that might be suggested by the historical continuity of ideas. The natural philosophers of previous ages were after all intelligent men, seeking after truth, and we shall be less close to historical prejudice if we assume that the answers they gave to the scientific problems that faced them were the best answers in the circumstances of their "factual" knowledge and their ideas of scientific procedure. Their scientific knowledge came from three major sources: authority, reason, and observation. Authority, *auctoritas*, was the work of the authors, *auctores*, principally the ancient writers who achieved immense standing in the West as fragments of a half-forgotten and superior civilisation. More simply the authorities were used in education, and most medical men never went beyond their education. This knowledge had exactly the same status as that taught to a modern medical student, who, like his predecessor, has no external reason to doubt the validity of what he is being taught. Only when he goes on to become a research scientist can he have an independent assessment of the truth of this knowledge. In this respect ancient science differed somewhat, for the distinction between teaching and research was not so clearly marked. We noted in an earlier article that there was sometimes confusion between teaching and discovery when Galen's remarks on "method" were being interpreted in the middle ages and renaissance, and although both Aristotle and Galen discuss the creation of new knowledge by discovery, it was often assumed that both of them knew as much as a man could know. In that case there could be *no* distinction between teaching and discovery for later ages, for "discovery" was simply the establishment of what the ancients had said, that is, teaching.

Yet the most erudite of the later natural philosophers knew that Aristotle and Galen had described scientific procedures that would lead to new knowledge by the work of later researchers. Yet these erudite men by inclination were bookish, and the least likely to put such precepts into action. They were, however, perfectly disposed to develop another aspect of scientific procedure they read about, that is "reason," the second of the sources of knowledge mentioned above. Aristotle had extensively formalised and practised the inductive mode of argument (from many particulars to general principles), and Galen had made remarks in the same vein in relation to case histories. Nevertheless, when reason was used in anatomy and physiology in the middle ages and renaissance it was invariably deductive, beginning with an axiom such as "nature does nothing in vain" or "opposites cure opposites," and ending with the necessary shape or function of a part. The reintroduction of inductivism, following Bacon and others, was a conscious part of methodological reform in the later renaissance.

Induction requires observation, the third of the sources of knowledge. Observational and inductive, the biological science of Harvey's predecessors such as Fabricius was on a level with that of Aristotle, but it was not yet modern science. Due weight was given to authority, which however was confirmed where possible by observation, and reason was used inductively to categorise and illuminate relationships between categories, such as analogous and homologous structures in animals. But modern science has an element lacking equally in Fabricius's science and in Aristotle's: experiment. Aristotle dissected animals, but this was but a small extension of the principle of observation. The Alexandrian anatomists and physiologists, however, vivisected animals and perhaps man. Vivisection is an extension of observation that almost reaches experiment, if we take experiment to be an abnormal manipulation of nature with a view to correlating the results with the new situation. In exploring the living body, the Alexandrians could hardly fail to notice distant and unexpected paralysis from cutting a particular kind of fibre, and it is clear that they soon began to look for the unexpected—that is, to experiment. Galen, following the Alexandrians, used experiment extensively and generally to good effect, as in his serial section of the spinal cord in the living animal. Here he was able to *begin* his procedure with experiment, cutting the cord, and relate the results, localised paralysis and loss of sensation, to the conclusion, the function and pathways of the nerves. The greater part of Galen's experiments, however, were used at the *end* of a chain of argument to confirm his own opinion or reject someone else's: useless to argue with the Erasistrateans, who always had some kind of reason for a counter-argument, so put the matter to the test, ligate and incise the artery to show that it contains blood. Where his own opinions are uncontested (perhaps because unknown) Galen does not support them with experiments. The cardiac septal pores were established by reason but not verified by experiment, whereas Galen does use a hydraulic experiment that would have been suitable for his purpose in connection with the disputed action of the kidney.

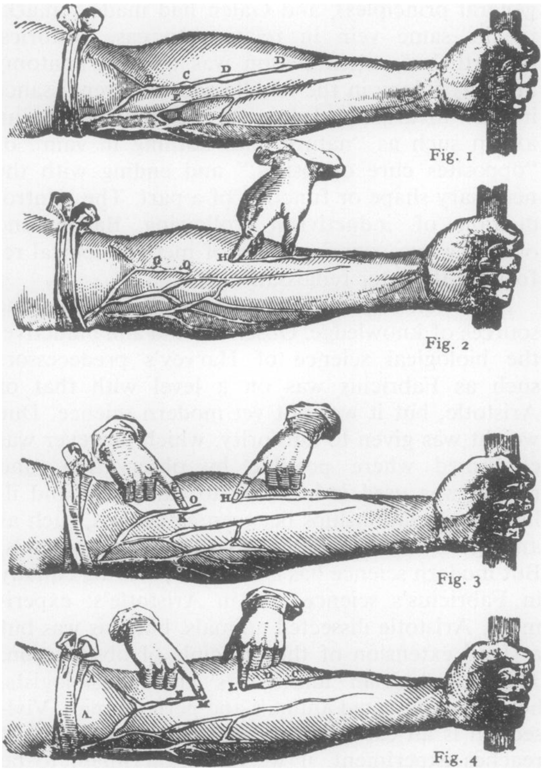

Figure *The only illustration used by Harvey in De Motu Cordis is this one, of an arm ligatured for phlebotomy. It is taken from a book by Fabricius, Harvey's teacher, who took it in turn from Bauhin's popular anatomical text. It shows veins swelling* distal *to the ligature, which prevents blood returning to the heart. According to pre-Harveian thought blood moved centrifugally from liver to extremities, and so the vein should have swelled on the* proximal *side of the ligature. Neither Fabricius, Bauhin, or any one else in the preceding two thousand years or so noticed the anomaly.*

Perhaps then modern medical science differs from that of Galen principally in this, that experiment is used wherever possible to confirm or falsify *every* hypothesis, and to throw up new evidence for further hypotheses. Additionally modern medicine relies much more on numerical evidence and mathematical reasoning. Colombo's discovery of the pulmonary transit was experimental, and Harvey's argument for the systemic circulation was partly quantitative, but there was no clear distinction between sense "experience" and "experiment" (the Latin *experimentum* can mean both) until after Newton, and little sophisticated use of experiment until Claude Bernard.

So the reason for the great continuity of ideas over the period covered by these articles was the lack of an adequate means of confirming or rejecting them. Ancient ideas formed not only the teaching curriculum, but the very means of thinking of the vast majority of educated physicians and natural philosophers. They were the stock-in-trade of the practising physician, the hallmark of his professionalism. Harvey himself suggests that it was this professional and social reason that accounted for Riolan's Galenism. Physicians assimilated the old ideas in the same way that food was assimilated in Galenic physiology, so that the ideas became part of them, and they literally could not see evidence that pointed in another direction. New structures, like the valves in the veins, were given old functions. Most remarkable of all, although letting blood had been practised throughout the period covered by these articles, so firm was the idea of a centrifugal flow of blood in the veins that no-one noticed that the veins swelled up on the *wrong side of the ligature* (see figure).

Notes and references

1 Pre-reformation universities had both civil and canon law.

2 Aristotle did not know of the nerves as structures distinct from other fibres. See the earlier articles in this series and Solmsen, F, Greek philosophy and the discovery of the nerves, *Museum Helveticum*, **18** (1961), 150–197.

3 See Peller, S, Harvey's and Caesalpino's role in the history of medicine, *Bull Hist Med*, **23** (1949), 213–235.

4 Caesalpino's important works are the *Quaestiones Peripateticae* and the *Quaestiones Medicae*. See also Pagel, W, *William Harvey's Biological Ideas*, Basel, 1967.

5 Hofmann, C, *Commentarii in Galeni De Usu Partium Corporis Humani*, Frankfurt-am-Main, 1625.

6 Worth mentioning in this connection is Plater, whose views on the equivalence of the spleen and the liver were versified by Pincierus, making a play with Plater's first name Felix ("happy")

Platerus! Happy thou art
In Name and in wit and in art.
Your doctrines invariably mean
High office enjoyed by the spleen

would be an unpoetical rendering. Pincierus, A, *Otium Marpurgense*, Herborn, 1614, p 160. Plater's views are concisely set out in his *De Corporis Humani Structura et Usu*, Basel, 1603.

7 Hofmann, C, *De Thorace*, Frankfurt, 1627.

8 Riolan, J, *Anthropographia*, Paris, 1618, pp 395–396.

9 Published in the Everyman edition of *De Motu Cordis* and his letters; *The Circulation of the Blood*, trans Franklin. Everyman, 1963.

10 Of course, Vesalius's purposes were not identical to those of the medical educators, but there does seem to have been a shift in the intellectual interest of the time from an analytical search for structure to a synthetic presentation of the whole man. The neoscholastic period was coincident with a general movement of return to authority in political, religious, and educational fields. See French, R K, *Anatomical education in a Scottish University*, Aberdeen, 1975, and Kearney, H, *Scholars and Gentlemen*, 1970.

11 Crooke, H, *Microcosmographia: A Description of the Body of Man. Together with the Controversies belonging thereto*, London, 1615.

12 Bauhin, C, *Institutiones Anatomicae*, Basel, 1609 (4th edition).

13 Du Laurens (Laurentius), A, *Historia Anatomica*, Frankfurt, 1602.

14 The reader is recommended particularly to Pagel (1967) and Whitteridge, G, *William Harvey and the Circulation of the Blood*, London, 1971.

15 Harvey, W, *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus*, Frankfurt, 1628.

16 Harvey, W, *Lectures on the Whole of Anatomy*, trans O'Malley, C D *et al*, Berkeley, California, 1961.

17 Harvey (1963) p 107; (1628) p 70.

18 Harvey (1628) p 23; (1963) p 28.

19 Harvey (1963) p 19.

20 Harvey (1628) p 18.

21 Harvey (1963) p 18.

22 Harvey (1963) p 57.

23 "ex concinno et diligenti valvularum et fibrarum artificio," Harvey (1628) p 41.

24 Harvey (1963) p 62.

25 *porositates pulmonum*. Harvey (1628) p 3.

26 Harvey (1963) p 186.

27 Harvey (1963) p 188.

28 Galen (1968) vol 1, p 303.

29 Reggio (Galen, *De Usu Partium Corporis Humani*, Paris, 1528) also uses the term, but it does not appear in Kühn's Greek text. See Galen *Opera Omnia*, Leipsig, 1821–33, vol 3, p 455, and Galen, *Opera Omnia*, (Junta) Venice, 1625, *prima classis*, 151v (used by Harvey).

30 Harvey (1961) p 68.

31 Harvey (1963) p 3.

32 Harvey (1961) p 54.

33 Harvey (1963) p 103.

34 Harvey (1628) p 67.

35 Harvey (1963) pp 156, 116.

36 See Keele, K, *William Harvey*, London, 1965, pp 103–106.

37 Harvey (1963) p 193 (the letter to Morison).

38 Harvey (1963) p 167 (to Riolan).

39 Harvey (1963) p 120.

40 Keele (1965) p 105. See also Entralgo, L, Harvey and scientific thought, *J Hist Med*, **12** (1957), 220–234.

41 Riolan, J, *Opera Anatomica*, Paris, 1649, p 433.

42 Riolan (1649) p 438. The italics are the present writer's.

43 Descartes, R, *Treatise of Man* (1664), ed and trans by Hall, T S, Cambridge, Mass, 1972.

44 Glisson, F, *Tractatus de Natura Substantiae Energetica*, London, 1672. See also Temkin, O, The classical roots of Glisson's doctrine of irritation, *Bull Hist Med*, **38** (1964), 297–328.

45 An excellent source for these changes in English physiology is Brown, T M, *The Mechanical Philosophy and the "Animal Oeconomy"—a Study in the Development of English Physiology in the Seventeenth and early Eighteenth Century*, Princeton University Ph D Thesis, 1968.

46 On the general influence of Newton, see Schofield, R E, *Mechanism and Materialism*, Princeton, 1970.

47 This sketch of the introduction of dynamic physiology has not been given detailed documentation as an extended treatment of the topic is due to appear in a book on Newton's ether edited by Cantor and Hodge.

48 Willis, T, *The Anatomy of the Brain and Nerves* (1664), ed Feindel, W, two vols, Montreal, 1965.

49 See French, R K, Sauvages, Whytt and the motion of the heart: aspects of eighteenth century animism, *Clio Medica*, **7** (1972), 35–54.

50 See, for example, Hutcheson, F, *Metaphysicae Synopsis*, Glasgow, 1742, published as used at Glasgow in the earlier eighteenth century, and Otto, M H, *De Elementa Juris Naturae et Gentium* (*Juris Divini Pars Altera*), Halae Magdeburgicae, 1738.

51 See French, R K, *Robert Whytt, the Soul and Medicine*, London, 1969.

52 Haller, A von, *Elementa Physiologiae*, eight vols, Lausanne, 1757–1766.